CLAIMS

We claim:

1. A method for determining the work of the heart of a living being, said method comprising determining the viscosity of the blood circulating within the living being.

2. The method of Claim 1 wherein said method comprises the steps of:

(a) measuring the viscosity of the circulating blood of the living being over a plurality of shear rates;

(b) detecting a pressure pulse of the heart of the living being; and

(c) determining the work of the heart from a combination of said viscosity of the circulating blood of, and the pressure pulse of the heart of, the living being.

3. The method of Claim 2 wherein said step of determining the work of the heart (WOH) is defined as:

$$WOH = \frac{\pi d^4}{128TL}\int_0^T \frac{P^2(t)}{\mu(t)}dt$$

where:

T is a period of one cardiac cycle;
P(t) is the pressure pulse of the heart;
d represents the average inside diameter of the entire vascular system from the heart to the vein;
L represents the average length of blood vessels from the heart to vein; and
$\mu(t)$ is said viscosity of the circulating blood over a plurality of shear rates.

4. A method for determining the rate of ejection of blood from the heart of a living being, said method comprising detecting a pressure pulse of the heart.

5. The method of Claim 4 wherein said method of determining the rate of ejection of the blood from the heart further comprises the step of determining the rate of change over time of said pressure pulse of the heart at the beginning of the pressure pulse.

6. A method for reducing endothelial cell dysfunction in a living being which is caused by oscillating flow of the circulating blood of the living being, said method comprising the step of reducing the rate of ejection of the blood from the heart of the living being.

7. The method of Claim 6 wherein said step of reducing the rate of ejection of the blood from the heart comprises administering a β-blocker to the living being.

8. The method of Claim 6 wherein said step of reducing the rate of ejection of the blood from the heart comprises minimizing or eliminating smoking by the living being.

9. The method of Claim 6 wherein said step of reducing the rate of ejection of the blood from the heart comprises minimizing or eliminating the ingestion of caffeine by the living being.

10. The method of Claim 6 wherein said step of reducing the rate of ejection of the blood from the heart comprises ingesting of alcohol by the living being.

11. A method for reducing endothelial cell dysfunction in a living being which is caused by oscillating flow of the circulating blood of the living being, said method comprising the step of reducing the viscosity of the circulating blood of the living being.

12. The method of Claim 11 wherein said step of reducing the viscosity of the circulating blood of the living being comprises administering blood viscosity reducing drugs to the living being.

13. The method of Claim 12 wherein said blood viscosity reducing drugs comprises cholesterol lowering drugs.

14. The method of Claim 11 wherein said step of reducing the viscosity of the circulating blood of the living being comprises administering fish oil to the living being.

15. The method of Claim 11 wherein said step of reducing the viscosity of the circulating blood of the living being comprises performing blood letting on the living being.

16. A method for reducing endothelial cell dysfunction in a living being which is caused by oscillating flow of the circulating blood of the living being, said method comprising the steps of reducing the rate of ejection of the blood from the heart of the living being and reducing the viscosity of the circulating blood of the living being.

17. A method for determining a hematocrit of blood circulating within a living being, said method comprising optically counting red blood cells in a known volume of the circulating blood where red blood cells and plasma have not been artificially separated.

18. The method of Claim 17 wherein said optically counting comprises:

(a) diverting the circulating blood through a transparent conduit of known dimensions; and

(b) analyzing an image of said diverted circulating blood through said transparent conduit to count the number of red blood cells in said diverted circulating blood.

19. An apparatus for determining the hematocrit of the circulating blood of a living being without having to separate red blood cells from the plasma of the circulating blood, said apparatus comprising an optical analyzer.

20. The apparatus of Claim 19 wherein said optical analyzer comprises:

a transparent conduit for conveying the circulating blood therethrough;

a light source for illuminating a predetermined portion of said conduit; and

red blood cell detector for counting the number of red blood cells passing through said illuminated predetermined portion of said conduit.

21. The apparatus of Claim 20 wherein said red blood cell detector comprises a charge coupled device and associated image processing software.

22. A method for determining a plasma viscosity of the circulating blood of a living being, said method comprising analyzing a single shear rate of flowing plasma, said plasma comprising a non-centrifuged sample of the circulating blood.

23. The method of Claim 22 wherein said analyzing comprises:

(a) providing a plasma sample in a first container at a first pressure level;

(b) providing a second container having a known initial internal pressure level lower than the first pressure level;

(c) establishing fluid communication between said first container and said second container via a lumen having known dimensions;

(d) detecting a rate of plasma volume change in said second container when said fluid communication is established; and

(e) determining the plasma viscosity from the rate of plasma volume change, the known dimensions of the lumen and a difference between the first pressure level and the intial internal pressure.

24. An apparatus for determining the viscosity of the plasma of the circulating blood of a living being without the need to centrifuge a portion of the circulating blood of the living being and utilizing single shear rate analyzer.

25. The apparatus of Claim 24 wherein said single shear rate analyzer comprises:

a first vacutainer for creating a plasma sample from the portion of the circulating blood and storing it at a known first pressure level;

a lumen having known dimensions;

a second vacutainer having a known initial internal pressure level lower than said first pressure level;

a detector for detecting the rate of volume change in said second vacutainer when said lumen is coupled between said first vacutainer and said second vacutainer; and

a calculator for determining the viscosity of the plasma from said rate of volume change, said known dimensions of said lumen and the difference of said first pressure level and said initial internal pressure.

26. The apparatus of Claim 25 wherein said first vacutainer comprises a porous medium therein that separates said first vacutainer into a first chamber and a second chamber, said first chamber for receiving a portion of the circulating blood of the living being therein and said porous medium retaining the red blood cells within said first chamber while permitting the plasma in said portion of the circulating blood to pass through into said second chamber.

27. The apparatus of Claim 25 wherein said calculator determines the plasma viscosity, μ_P, utilizing the following equation:

$$\mu_P = \frac{\pi d^4 \Delta P}{128 Q L},$$

where:

d is the inner diameter of said lumen;
L is the length of said lumen
Q is said rate of volume change; and
Δp is said difference of said first pressure level and said initial internal pressure.

28. A method for estimating blood vessel wall shear stress in high and low shear areas of a blood vessel bifurcation of a living being by correlating a blood viscosity parameter with a blood pressure parameter.

29. The method of Claim 28 wherein said step of correlating a blood viscosity parameter with a blood pressure parameter comprises the steps of:

(a) determining a first viscosity profile of the circulating blood of the living being over a plurality of shear rates and a second viscosity profile of the circulating blood of a healthy living being over said plurality of shear rates for use as a reference;

(b) defining a blood viscosity parameter that comprises:

(1) a high shear rate blood viscosity component based on high shear rate blood viscosity values from said first and second viscosity profiles;

(2) a low shear blood viscosity component based on low shear rate blood viscosity values from said first and second viscosity profiles; and

(3) a component representing the thrombotic tendency of the blood;

(c) defining a blood pressure parameter that comprises:

(1) an average blood pressure term; and

(2) a rate of ejection of blood from the heart of the living being; and

(d) providing a matrix having a plurality of said blood viscosity parameters along a first axis of said matrix and a plurality of said blood pressure parameters along a second orthogonal axis and wherein the intersection of any one of said plurality of said blood viscosity parameters and any one of said plurality of said blood pressure parameters specifies a particular high wall shear stress and low wall shear stress.

sub C1 30. The method of Claim 29 wherein said high shear rate blood viscosity component comprises a ratio of a blood viscosity value from said first viscosity profile at a high shear rate to a blood viscosity value from said second viscosity profile at said high shear rate.

31. The method of Claim 29 wherein said low shear rate blood viscosity component comprises a ratio of a blood viscosity value from said first viscosity profile at a low shear rate to a blood viscosity value from said second viscosity profile at said low shear rate.

32. The method of Claim 29 wherein said component representing the thrombotic tendency of the blood comprises a ratio between an angle formed between said first and second viscosity profiles to a predetermined value.

33. A method for analyzing the viscosity of the circulating blood of a living being, said method comprising the steps of:

(a) determining viscosity data of the living being's circulating blood for a plurality of shear rates over a test run time;

(b) segmenting said test run time into a plurality of time segments; and

(c) generating a blood viscosity profile for each of said time segments from the beginning of said test run until the end of each of said time segments.

34. The method of Claim 33 further comprising the steps:

(a) plotting each of said blood viscosity profiles on a common log viscosity vs. log shear rate graph; and

(b) utilizing the spatial relationships between each of said blood viscosity profiles for diagnostics and treatment of the living being.

35. The method of Claim 34 further comprising the steps of developing and testing drugs that alter the living being's blood viscosity to achieve Newtonian type performance at high shear rates.

36. The method of Claim 34 further comprising the step of obtaining coagulation and clotting information from blood viscosity profiles.

37. An apparatus for automatically determining the surface tension of the circulating blood of a living being, said apparatus comprising a blood column height determinator based on capillary rise.

38. The apparatus of Claim 37 wherein said column height determinator comprises:

a lumen having a first end vented to atmosphere and a second end coupled to one port of a valve, said valve having a second port coupled to a source of circulating blood of the living being;

a reservoir, vented to atmosphere, having an input coupled to a third port of said valve;

a detector for monitoring a fluid level in said lumen; and

wherein said valve is first operated to direct the circulating blood into said lumen to form a column of blood and wherein said valve is then operated to isolate said circulating blood from said lumen while coupling said lumen and said reservoir in fluid communication to form a falling column of blood in said lumen, said detector detecting the final position of said falling column of blood.

39. The apparatus of Claim 38 wherein said apparatus further comprises an overflow reservoir in fluid communication with said first reservoir through an aperture, said overflow reservoir collecting blood that exceeds a predetermined volume of blood in said reservoir from said falling column.

40. The apparatus of Claim 39 wherein said detector is positioned at a predetermined height above said aperture.

41. The apparatus of Claim 40 further comprising a processor for calculating the surface tension of the circulating blood according to the following:

$$\sigma = \frac{\rho dhg}{4},$$

where:

σ = surface tension (N/m)

ρ = blood density (g/m^3)
d = lumen inside diameter (m);
h = the distance between said aperture and said final position of said falling column of blood (m); and
g= gravitational constant.

42. A method for determining whether a drug reduces or increases the surface tension of the circulating blood of a living being, said method comprising the steps of:

(a) determining the surface tension of the circulating blood of a living being utilizing a blood column height determinator based on capillary rise;

(b) administering a drug to the living being; and

(c) re-determining the surface tension of the circulating blood of the living being utilizing said blood column height determinator to see the change in the surface tension.

43. A method for improving blood perfusion to the lower extremeties of a living being experiencing peripheral arterial disease, said method comprising the steps of:

(a) determining the viscosity of the circulating blood of the living being over a range of shear rates;

(b) reducing the viscosity of the circulating blood by administering a substance to the living being or by blood letting; and

(c) re-determining the viscosity of the circulating blood of the living being over said range of shear rates to verify said reduction in the viscosity.

44. An apparatus for determining the deformability of red blood cells of the circulating blood of a living being, said apparatus comprising a plurality of tubes closely adjacent one another and each having an inner diameter different from its neighbor, each of said plurality of tubes having an opening exposed to a flow of circulating blood and each of said tubes being closed at its other end for collecting red blood cells therein.

45. The apparatus of Claim 44 wherein said plurality of tubes are arranged sequentially from the smallest inner diameter to the largest inner diameter.

46. The apparatus of Claim 44 wherein the inner diameters of said plurality of tubes is within the range of 1μm to 10μm.

47. The apparatus of Claim 44 further comprising:

an illuminator for passing light through each one of the plurality of tubes as they collect red blood cells in accordance with their respective inner diameters and wherein respective light rays, of varying degrees of redness corresponding to the amount of red blood cells collected in each of said plurality of tubes, emerge from said plurality of tubes; and

a redness color detector for detecting the degree of redness of each of said emerging light rays corresponding to each of said plurality of tubes.

48. An apparatus for detecting the lubricity of the circulating blood of a living being as the blood travels through the vascular system of the living being, said apparatus comprising:

(a) a transparent tube for passing a falling column of the circulating blood of the living being;

(b) an illuminator for directing light at a portion of said transparent tube that contains a residue left by said falling column;

(c) a detector for detecting any light that passes through the transparent tube and residue and generating corresponding detection data; and

(d) calculator for receiving said detection data and generating a lubricity value based on said detection data.

49. The apparatus of Claim 48 wherein said detector comprises a charge coupled device chip that generate pixel Gray scale values for said detection data.

50. The apparatus of Claim 49 wherein said calculation means comprises a processor and wherein said processor averages all of said pixel Gray scale values to generate said slipperyness value.

51. An apparatus for effecting the viscosity measurement of circulating blood in a living being, said apparatus comprising:

a lumen arranged to be coupled to the vascular system of the being;

a pair of tubes having respective first ends coupled to said lumen for receipt of circulating blood from the being, one of said pair of tubes comprising a capillary tube having some known parameters;

a valve for controlling the flow of circulating blood from the being's vascular system to said pair of tubes; and

an analyzer, coupled to said valve, for controlling said valve to permit the flow of blood into said pair of tubes whereupon the blood in each of said pair of tubes assumes a respective initial position with respect thereto, said analyzer also being arranged for operating said valve to isolate said pair of tubes from the being's vascular system and for coupling said pair of tubes together so that the position of the blood in said pair of tubes changes, said analyzer also being arranged for monitoring the blood position change in at least one of said tubes and calculating the viscosity of the blood based thereon, said analyzer comprising an indicator that generates an indication as to movement of the blood in at least one of said pair of tubes.

52. The apparatus of Claim 51 wherein said indicator comprises a flashing light whose flash rate is proportional to the movement of blood in at least one of said pair of tubes.

53. The apparatus of Claim 51 wherein said indicator comprises a speaker and a sound card that generate a sound having a frequency that is proportional to the movement of blood in at least one of said pair of tubes.

54. An apparatus for effecting the viscosity measurement of circulating blood in a living being, said apparatus comprising:

a lumen arranged to be coupled to the vascular system of the being;

a pair of tubes having respective first ends and second ends, said first ends being coupled together via a capillary tube having some known parameters;

a valve for controlling the flow of circulating blood from the being's vascular system to said pair of tubes, said valve being coupled to a second end of one of said pair of tubes and being coupled to said lumen; and

an analyzer, coupled to said valve, for controlling said valve to permit the flow of blood into said pair of tubes whereupon the blood in each of said pair of tubes assumes a respective initial position with respect thereto, said analyzer also being arranged for operating said valve to isolate said pair of tubes from the being's vascular system so that the position of the blood in said pair of tubes changes, said analyzer also being arranged for monitoring the blood position change in at least one of said tubes and calculating the viscosity of the blood based thereon, said analyzer comprising an indicator that generates an indication as to movement of the blood in at least one of said pair of tubes.

55. The apparatus of Claim 54 wherein said indicator comprises a flashing light whose flash rate is proportional to the movement of blood in at least one of said pair of tubes.

56. The apparatus of Claim 54 wherein said indicator comprises a speaker and a sound card that generate a sound having a frequency that is proportional to the movement of blood in at least one of said pair of tubes.